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Food miles emissions lower than previously estimated but differ strongly across commodities

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Abstract

Previous estimates of food transport emissions vary widely, fueling debate about their contribution to agrifood emissions. Using food supply data and multimodal transport networks, we estimate global food transport emissions at ~0.82 GtCO2 annually (2019-2023), lower than previous food-miles-based estimates and consistent with national greenhouse gas inventories. Emissions are concentrated in domestic transport and a few countries and commodities, highlighting where targeted mitigation efforts could most effectively reduce food transport emissions.

Introduction

Agrifood systems contribute roughly one-third of global anthropogenic greenhouse gas emissions[1,2]. Food transportation—often called “food miles”—is a key component of agrifood emissions, yet previous estimates show widely divergent estimates[3,4]. This divergence has fueled debates about whether local sourcing of food yields considerable emissions savings or whether the current production system of large producers and a considerable reliance on international shipments is more beneficial from an emissions standpoint.

The divergence in previous estimates of food miles emissions stems in part from differences in system boundaries and methodological assumptions, each offering distinct strengths. The multiregion input–output model–based (MRIO) approaches[3] capture upstream transport emissions (often referred to as indirect emissions, for instance from fertilizers and other inputs) embedded along supply chains, including international food transportation. These approaches estimate food transport emissions at 1.4 $GtCO_2e$ in 2017 when upstream emissions are included, or around 1.1 $GtCO_2e$ when only direct emissions (i.e., domestic and international transportation of food) are considered. However, they do not explicitly model multimodal transportation routes between producing and consuming regions and instead use simple geographical distances.

Official estimates from the United Nations Food and Agriculture Organization (FAO) of 0.47 $GtCO_2$ in 2017 are based on a fraction of total domestic transport emissions, derived using country-specific estimates for the US, China, and the EU, and global proxy estimates from EDGAR-FOOD for all other countries[4,5]. However, these estimates do not include international food transport emissions and lack commodity-level estimates. In contrast, EDGAR-FOOD estimates emissions at 0.8 $GtCO_2e$, using a similar fractional allocation approach but with different shares, and including international transport[1]. However, both approaches allocate fixed shares of national transport emissions to food systems, rather than explicitly modelling commodity-level trade routes and transport modes, limiting their ability to resolve heterogeneity in supply-chain structure and transport pathways.

More detailed bottom-up life cycle assessments for the United States and the European Union point to widely varying transport-related emissions across commodities and regions, depending on factors such as distance, mode of transport, and country-specific emissions factors[6], which none of the above-

mentioned approaches can explicitly capture, due to a lack of granularity in the underlying national data used.

Here, we provide refined estimates of food transport emissions by combining physical trade flow and food balance sheet data with least-cost, multimodal transportation networks. Our approach explicitly accounts for where food is grown within a country, international exports and re-exports, processed commodities, and estimates transport distances and emissions across road, rail, and maritime shipping using least-cost paths and region-specific emission factors. By capturing multimodal and spatial heterogeneity in food transport systems, we provide new estimates of domestic and international food transport emissions (i.e., capturing both hinterland transportation and transport across borders). Our food transport emissions account for re-exports of food commodities (see Methods) but exclude upstream emissions from fertilizers and other inputs. We take a consumer perspective when linking emissions to individual countries and capture only CO_2 emissions (roughly 93% of all greenhouse gases from transport[7]).

International food travels farther but emits less than domestic transport

We estimate that global food-transport emissions averaged 0.82 $GtCO_2$ yr^{-1} over 2019–2023 (Fig. 1a). Internationally traded food accounted for 16.70 trillion tonne-kilometres (3.64 billion tonnes) on average between 2019 and 2023, which is 20% more than the 13.97 trillion tonne-kilometres (7.59 billion tonnes) moved domestically. Yet this relationship inverts for emissions for the same time period; international trade contributes 0.30 $GtCO_2$ to total emissions compared with 0.52 $GtCO_2$ from domestic transport. In other words, food crossing borders generates roughly half the emissions despite travelling considerably further. This counterintuitive pattern reflects fundamental differences in transport mode. International trade relies predominantly on maritime shipping, which emits on average 15 g CO_2 per tonne-kilometre, including land-based hinterland transport. Domestic distribution depends heavily on road and rail freight. Our estimates suggest that road transport is roughly 4.5 times more carbon-intensive per tonne-kilometre than maritime, while rail emissions intensities are comparable to maritime once the hinterland component is included.

These findings underscore the value of multimodal transport modelling in agrifood emission accounting. By integrating mode and country-specific emissions factors, our approach reveals that distance alone is a poor proxy for emission intensity, and that policies targeting food-transport emissions must account for how food moves, not merely how far.

Food transport emissions based on food miles are lower than those previously estimated

Using 2017 as a base year, to be comparable to previous estimates, our estimate of 0.77 $GtCO_2$ is nearly half (or two-thirds if only downstream emissions are considered) of 2017 food-transport emissions inferred from the MRIO approach, but compares well with EDGAR-FOOD (0.79 $GtCO_2e$) (Fig. 1b). Unlike EDGAR-FOOD and MRIO, our estimates do not account for non-CO_2 emissions. Moreover, our 2017

estimates of 0.49 $GtCO_2$ for domestic emissions closely align with FAO post-farmgate transport estimates that exclude international flows (0.47 $GtCO_2$).

Considering that emissions from the agrifood system (excluding food miles) are in the order of 16-18 $GtCO_2e$ for the year 2017, our estimate suggests that food miles are approximately ~4.6-5.3% of total agrifood system emissions over the same period.

A small set of commodities contributes disproportionately to transport emissions

Twenty-two commodities account for 80% of total food-transport emissions (Fig. 2a). The top eight—maize, cattle milk, soy, wheat, rice, palm oil, sugar aggregates (which include refined sugar, molasses, and other sugar products), and potatoes—alone contribute 60% of total emissions, with maize standing out as the single largest contributor with over 0.10 $GtCO_2$ annually (Fig. 2b). These high-volume food commodities are transported extensively, with milk as a notable exception due to emissions from refrigerated transport. Notably, domestic transport dominates emissions for globally traded staples and international transport emissions for global vegetable oils (Fig. 2b), reinforcing that domestic miles within countries often matter more than long haul across oceans for food staples.

Emission reduction in a handful of countries can reduce global emissions

Food-transport emissions exhibit extreme cross-country heterogeneity in both absolute and per-capita terms (Fig. 3a-b). In absolute terms, eleven countries contribute 70% of total food-transport emissions. Large food consumers—China, the United States, India, Brazil, and Russia—dominate global totals, with domestic transport accounting for the majority of their emissions, broadly consistent with previous studies, although India is replaced by Japan. In contrast, per-capita emissions are highest among small island nations (such as Saint Lucia, Marshall Islands), where reliance on international shipping (using small, carbon-intensive vessels) inflates individual footprints. Per capita emissions are also substantial in highly import-dependent countries (such as Qatar, New Zealand, Oman, and Singapore) and in sparsely populated countries (including Canada, Russia, and the United States). The lowest per-capita emissions occur in landlocked or low-income countries with limited trade integration. These patterns reflect the interplay of geography, population size, agricultural production, trade dependence, and transport infrastructure. The skew in country-level emissions and the dominance of domestic transport imply that decarbonization efforts, by electrifying transport or providing green fuels, in a few high-emitting countries, could substantially reduce global food transport emissions.

Our results underscore that how food moves matters more for emissions than how far it travels, challenging distance-based assumptions often embedded in debates on local sourcing and food miles. By revealing where transport emissions are most concentrated across commodities and countries, this work can help identify mitigation opportunities that can deliver disproportionate reductions in food transport emissions.

Methods

Transport Modelling and Emissions Calculation

We estimate CO_2 emissions from transporting food between ~3,500 global administrative regions by combining a spatially explicit multimodal transport model with mode-specific emission factors (CO_2 per ton-km). This builds on the multimodal food transport model of Verschuur et al. (2025)[8] which simulates least-cost domestic and international transport routes for food flows by representing production sites, consumption centers, transport networks (road, rail, maritime, air), and modal choices. For each origin–destination pair, the model estimates the most likely transport route and mode, breaking it down into individual legs, including intermodal transfers at ports, airports, and railway stations.

Emissions are calculated by applying mode-specific emission factors to each transport leg and aggregating these emissions across all legs and subnational origin–destination flows. Maritime emissions per route (between two pairs of ports) are derived from vessel-specific factors from Verschuur et al. (2024)[9], which account for ship type, size, and operational speed. For each maritime connection, the model assigns a representative vessel class based on observed traffic and applies the corresponding factor; emissions from auxiliary engines and port activities are excluded.

Inland transport networks, which serve domestic supply, international land-based transport, and field-to-port/airport movements, include both road and rail transport, with country-specific emission factors from the International Energy Agency (IEA) Mobility Model[10] reflecting fleet composition, fuel mix, energy intensity, and, for rail, electricity generation. Emissions are computed separately for each country segment along a route. Air transport emissions use a global average from the IEA Mobility Model, which is appropriate given the limited variation in long-haul aircraft performance. We exclude intermodal transfer and handling emissions for all modes.

Estimation of food transport emission factors

Emissions for all transport legs were then aggregated to the origin–destination–commodity level. Food miles emissions between subnational routes were aggregated to nationally representative emissions factors using flow propensity weights, calculated as the product of origin production shares and destination population shares, with commodity-specific subnational production from gridded crop[11], livestock[12], and population[13] maps. For each origin–destination–mode combination, this results in weighted average emission intensities ($kgCO_2$/tonne) for tank-to-wheel emissions, alongside transport distances. For perishable commodities (meat, dairy, eggs, fresh fruits, vegetables, and others), emission factors were adjusted using refrigeration multipliers: 1.15× for land transport[14] and 1.70× for maritime reefer containers[14], reflecting cold chain energy requirements.

Physical Food Flow Data

Using the FAO detailed trade matrix and production data, we estimate for the years 2017–2023 physical food flow data, capturing both domestic production and international trade. The food flow data is developed following the approach of Kastner et al. (2011)[15]. This approach allows–in a balanced way that avoids double counting–distinguishing products that are consumed domestically from products that enter international supply. It crucially assumes that a country's domestic consumption and exports are proportionally supplied by its domestic production and its imports. Details on the implementation of the approach can be found in Schwarzmueller and Kastner (2022)[16]. The resulting food flow data tracks, for 209 countries and 207 primary commodities, the country where the product (in primary or derived form) is produced and the country where it is ultimately used–whether as food, feed, or for non-food/non-feed purposes. We assign transport emissions to the latter, i.e. the consumer country.

Consumption- and commodity- food transport emissions

For each origin–destination–commodity flow, the total food transport emissions were calculated as:

$E_{c,i,j,m} = V_{c,i,j} \times S_{c,i,j,m} \times EF_{c,i,j,m}$

where $E_{c,i,j,m}$ is the transport emissions (tCO_2) for commodity c from origin i to destination j by mode m (air, maritime, land, or domestic), $V_{c,i,j}$ is the physical food flow volume (tonnes) for commodity c from origin i to destination j, $S_{c,i,j,m}$ is the share of food flow volume transported by mode m from the Verschuur et al. (2022)[17], and $EF_{c,i,j,m}$ is the mode-specific emission factor ($kgCO_2$ per ton) for commodity c from origin i and to destination j by mode m.

Total emissions for each flow are then calculated by summing across all modes:

$E_{c,i,j,m} = \sum_m EF_{c,i,j,m}$

Food miles were computed as flow-weighted distances (tonne-kilometres). Country-level consumption and commodity-level emissions were estimated by aggregating across all supplying regions and commodities, respectively, while distinguishing between domestic and international flows.

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Figures

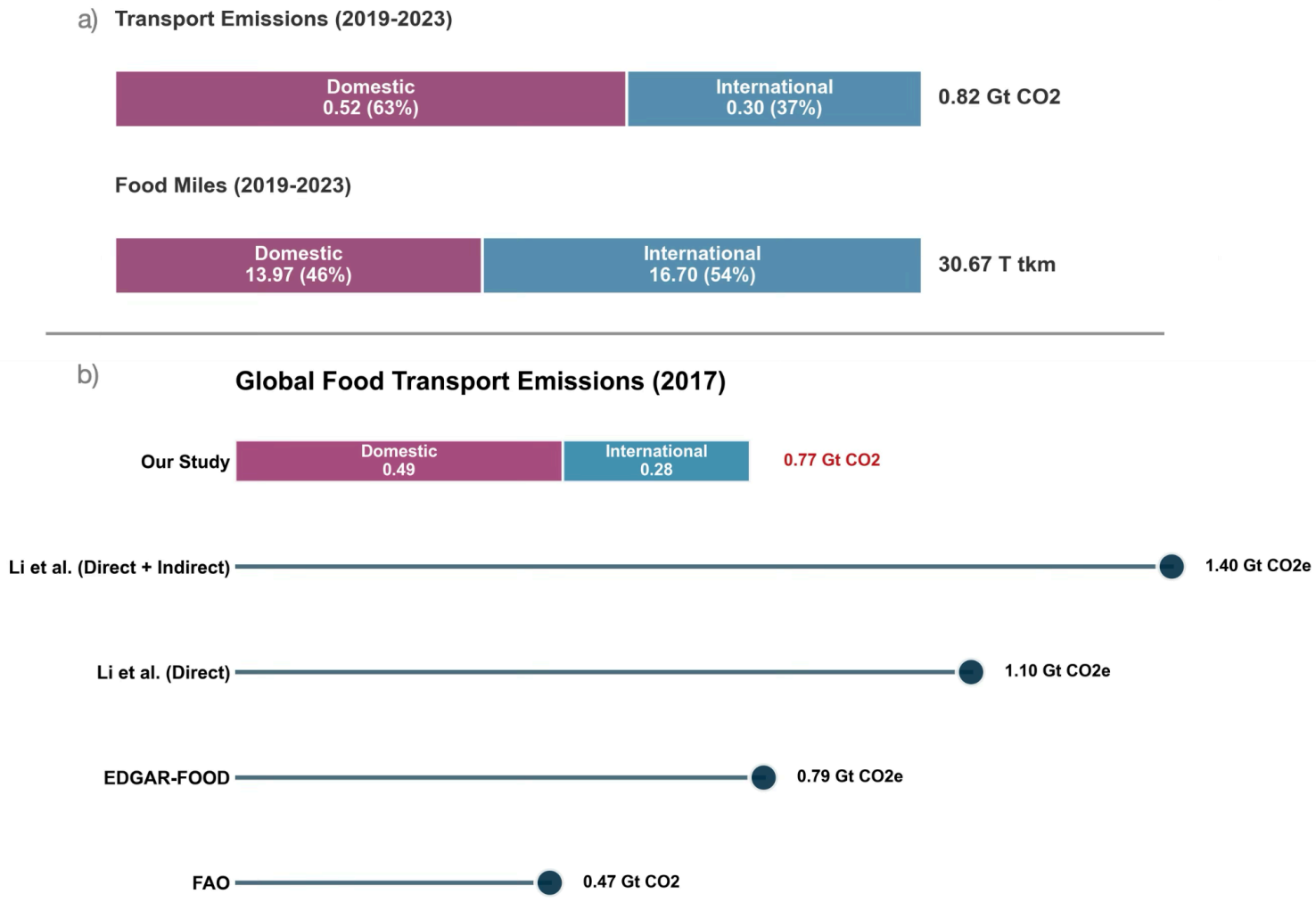


Figure 1

Global food-transport emissions and domestic vs. international breakdown. (a) Breakdown of average emissions (top) and tonne-kilometres (bottom) between 2019 and 2023 by domestic (in magenta) and international (in blue) food transportation. (b) Global food-transport emission estimates from different methodological frameworks for the year 2017.

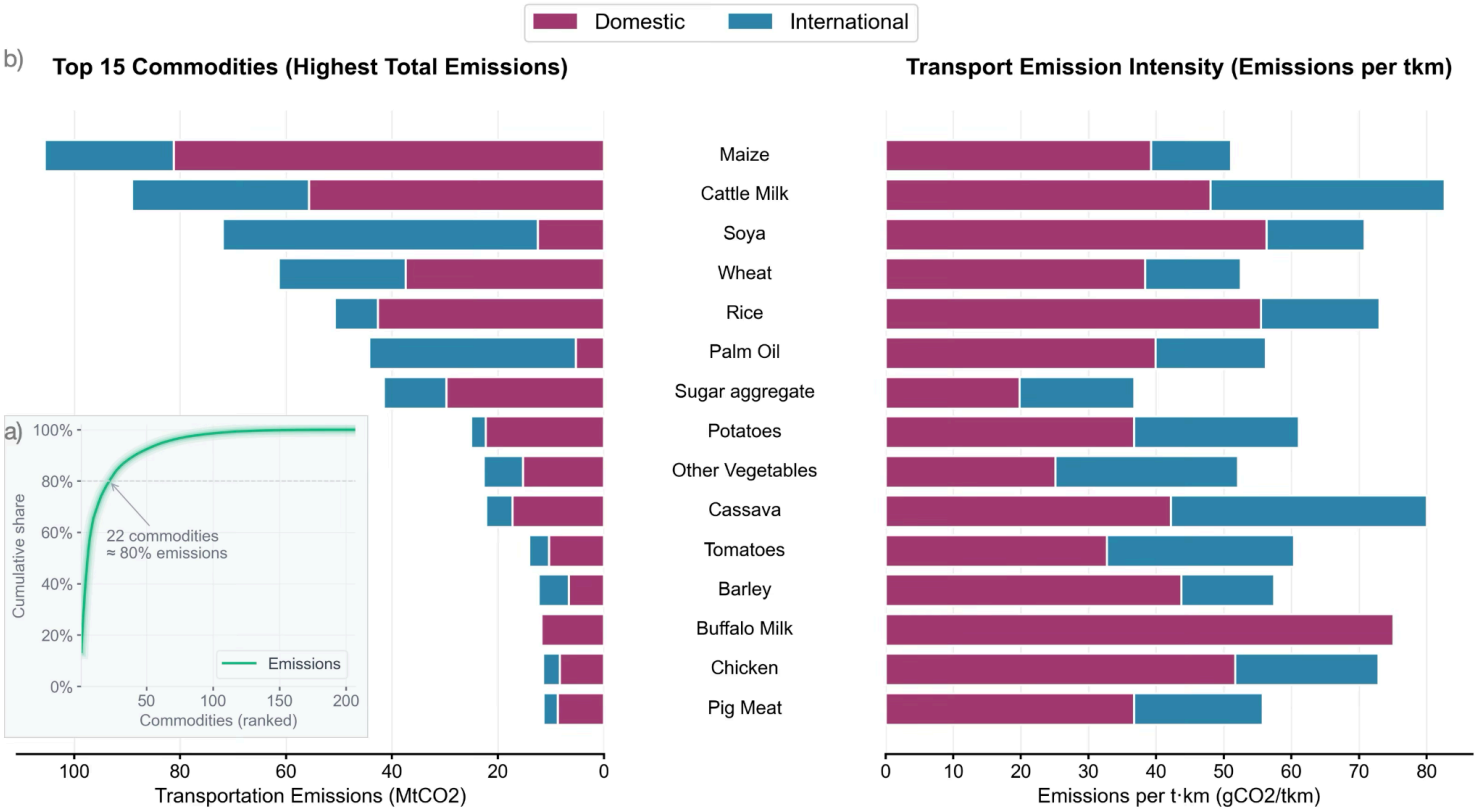


Figure 2

Food-transport emissions by commodity. (a) Contribution of food commodities to total food transport emissions, averaged over 2019 to 2023. (b) Top 15 commodities by total average transport emissions ($MtCO_2$) and their transport emission intensities ($gCO_2t^{-1}km^{-1}$) for 2019 to 2023, with disaggregation by domestic (magenta) and international (blue).

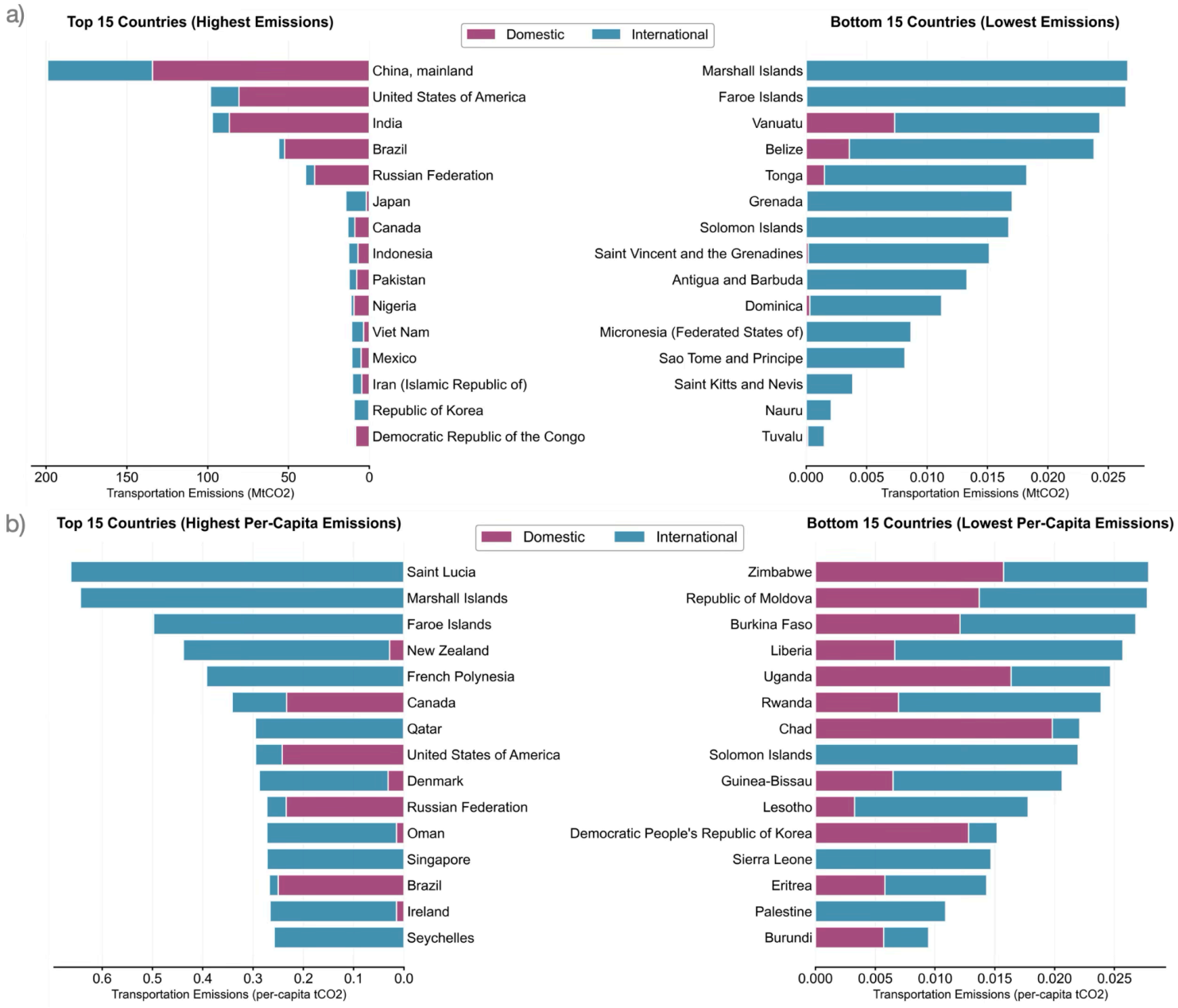


Figure 3

Consumption-based food transport emissions by country. (a) Top 15 and bottom 15 countries by average total food-transport emissions ($MtCO_2$) for 2019-2023, disaggregated by domestic (magenta) and international (blue) contributions. (b) Top 15 and bottom 15 countries by per-capita food-transport emissions (tCO_2 per capita).